An Exploration of Age Effects on a Memory plus Visuomotor Dual Task Paradigm

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Contents

Abstract

Several studies have described a dual task deficit in patients with dementia, which does not occur in healthy ageing. Attempts to create a dual task suitable for clinical use have encountered various problems, and have led to the development of a dual task which employs a digit recall memory task concurrently with a visuomotor tapping task, using a specially designed Fitts' Law Box. To explore the age effects associated with, and effectiveness of, this dual task, and to investigate its suitability for clinical use, 24 healthy elderly and 25 healthy young participants were assessed on two conditions using the dual task apparatus and several tests of executive function and memory. In contrast to previous dual task studies, a significant effect of age was found on both dual task conditions, as well as the measures of executive function and memory. These findings suggest that the dual task is unsuitable for clinical use. Possible explanations for these findings are discussed, along with suggestions of modifications for the Fitts' Law Box.

1. Introduction and Literature Review

1.1. Introduction to Working Memory

In 1974, Alan Baddeley and Graham Hitch proposed a multimodal system to replace the concept of a singular short term memory store. They termed this system *working memory*, emphasising its functional capabilities as opposed to being simply a temporary storage vessel. Working memory is "a limited capacity temporary storage system that underpins complex human thought" (Baddeley, 2007, p. 7). While the term *short term memory* continues to be used to describe the capacity to temporarily retain information for several seconds, working memory indicates the involvement of attentional control and the manipulation of information held in short term storage.

The original multi-component model (Baddeley & Hitch, 1974) consisted of a limited capacity system of attentional control named the central executive, and two ancillary limited capacity storage systems named the phonological loop and the visuospatial sketchpad. The phonological loop was explained as consisting of a phonological store in which auditory or speech-based information is held and is subject to rapid decay, and an articulatory rehearsal component that can revive memory traces through subvocal rehearsal. Functioning similarly, the visuospatial sketchpad holds visual and spatial information separately, with the visual aspects relating to patterns and objects, and the spatial aspects relating to locations. The central executive was vaguely explained as a system controlling executive functions such as planning and decision making (Baddeley, 1996).

The proposition of the original working memory model (Baddeley & Hitch, 1974) stimulated a variety of research in the ensuing years, with the two slave systems receiving much of the focus (Baddeley, 1996). In the mid 1980's, however, the study of the central executive began in depth. Baddeley's (1986) speculations on the functions of the central executive were based heavily on Norman and Shallice's (1986) model of attentional control of action, which proposed the control of behaviour on two levels; one is based on habits and schemas, and is somewhat automatic; the other is a mechanism for inhibiting and overriding such automatic responses termed the Supervisory Attentional System (SAS).

In 2000, Alan Baddeley added a fourth component to the multimodal model of working memory; the episodic buffer is assumed to act as an interface between the working memory subsystems and long term memory (Figure 1). It was described as a temporary storage system that can link visual, verbal and perceptual information from long term memory, semantic and episodic memory (Baddeley, 2000).

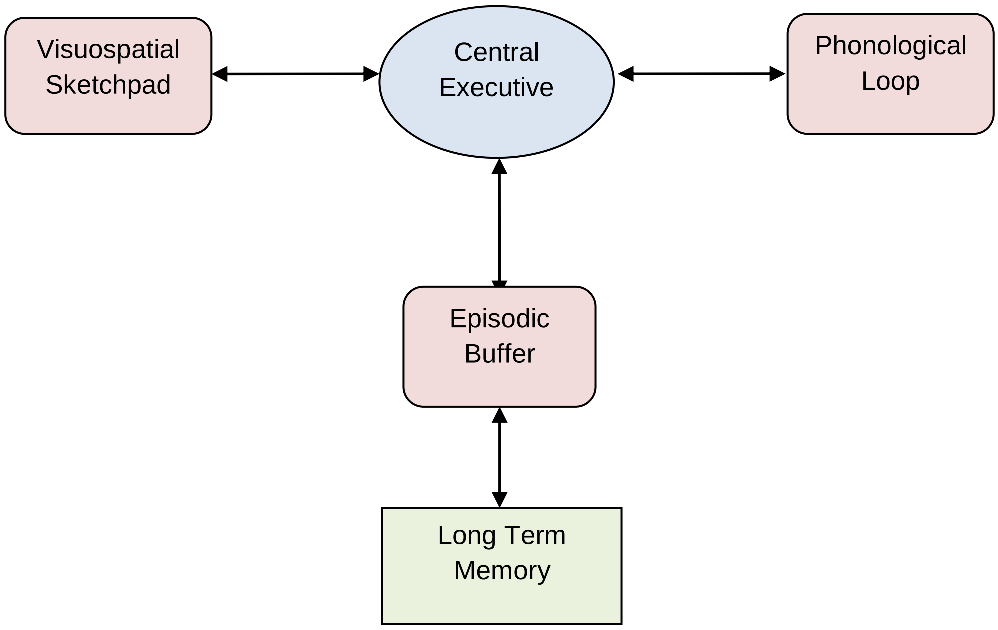

Figure 1. Diagram of working memory (adapted from Baddeley, 2000).

1.2. The Dual Task Paradigm

1.2.1. Dual Task Performance

The first executive function to be researched was the ability to coordinate information from the two slave systems. Baddeley, Logie, Bressi, Della Sala, and Spinnler (1986) noted that test results from Alzheimer's disease patients indicated a working memory deficit as opposed to a short-term memory deficit. They proposed in particular a central executive dysfunction, which would result in poorer learning ability and poorer performance on span tasks relying partly on the central executive. It was predicted that reduced performance from the central executive would lead to difficulty coordinating two concurrent tasks, and so Baddeley et al. (1986) devised a dual tasking study to measure coordination performance on two simultaneous tasks; one task tapping in to the visuospatial sketchpad, the other drawing upon the phonological loop. By ensuring that the two tasks would not interfere directly with one another, any deficit in the dual task experiment could be attributed to the coordination mechanism of the central executive. The study was carried out on patients with mild to moderate Alzheimer's disease (AD), healthy controls matched closely for age and background, and a group of young healthy controls, in order to compare the effects of normal ageing and dementia.

The study comprised one primary task and three secondary tasks. The primary task was a test of pursuit tracking, and involved tracking a moving white square on a coloured monitor using a light-pen. The speed of the square's movement was gradually increased until the participant was unable to accurately track the square for more than 60% of the time, thus equating performance between participants. The secondary tasks were combined with the tracking task one at a time. The first of the secondary tasks was articulatory suppression, which puts minimal demand on the central executive and involved repeatedly counting from one to five at a steady pace. The second was a test of reaction time when a tone was heard, using a footswitch to respond to a tone played at intervals of between 4s and 6s. This puts a higher level of demand on the central executive, and is thought to indicate a person's attentional capacity, although task difficulty cannot be equalised across groups. Thus in order to avoid the argument that AD patients may perform poorer than controls in the reaction time task because they found the task harder, the third of the secondary tasks was concurrent digit span which puts considerable demand on the central executive. Each individual's digit span was established prior to use in the dual task, ensuring difficulty level was equated. To calculate digit span, participants heard numbers presented at a rate of one digit per second and immediately recalled the digits in the correct order. Number strings were increased by one digit, and three presentations were made at each string length, until the participant could no longer recall two out of three sequences at a particular length.

The results of Baddeley et al.'s (1986) study were striking (Figure 2). They found that the addition of a second concurrent task was more disruptive to the AD patients compared to either control group, even when the same level of task difficulty was maintained across groups. There was found to be a small dual task effect for the secondary task of articulatory suppression, whereas the synchronized reaction time task resulted in a considerably impaired performance by the AD patients compared with both control groups. Similarly the digit span task, equated for difficulty across groups unlike the reaction time task, produced a significantly impaired performance from the dementia patients but not from either control group. When the healthy elderly group were compared against the young controls, no significant difference was found between their performance ability on the secondary tasks, indicating the tasks had been successfully equated for difficulty level across groups, hence making dual task performance directly comparable between groups. Results of the primary tracking task showed that despite achieving the same level of accuracy across groups, the elderly controls carried out the task at a significantly lower difficulty level than the younger controls, and the AD group had the task set to a significantly lower level than the elderly group. Baddeley et al.'s (1986) findings agree with the hypotheses that the central executive is necessary for coordinating the concurrent performance of two or more tasks, and that patients with Alzheimer's disease display a selective deficit in central executive functioning.

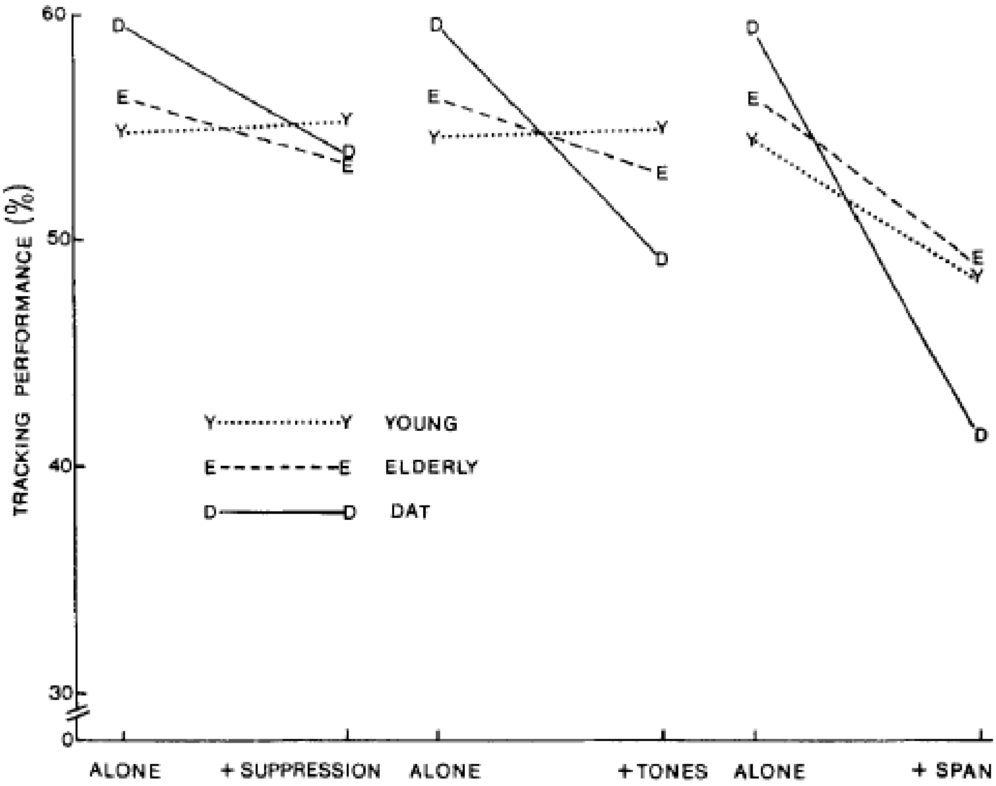

Figure 2. Graph of results found by Baddeley et al. (1986).

1.2.2. Ability over Time

As the central executive is assumed to be responsible for the coordination of dual tasking but is damaged in early Alzheimer's disease, Baddeley, Bressi, Della Sala, Logie, and Spinnler (1991) predicted that central executive functioning would decline further with disease progression. This would be seen through a further drop in dual tasking ability compared to performance at the earlier stage of disease. In order to test this, Baddeley et al. (1991) carried out a longitudinal study involving the AD patients and controls who participated in the Baddeley et al. study in 1986. By using the same participants, and the same tests, individual performance was compared with their own previous performance, leading to a more accurate observation of decline in dual tasking ability than when comparing separate groups of individuals. All participants were tested on three occasions at six month intervals further to the original tests.

The results from the follow-up study confirmed the hypothesis; each of the three secondary tasks showed a systematic decline in performance over the three testing occasions for the AD patients while the results for the single tasks showed no decline in performance across the same time span. In comparison, the elderly control group showed no change in single task or dual task performance level across the testing sessions. This is further evidence that patients with AD have difficulty coordinating two concurrent tasks, consistent with a central executive deficit (Baddeley et al., 1991).

1.2.3. Replication of the Decrement with Different Dual Tasks

Several replications of Baddeley et al.'s (1986; 1991) studies have demonstrated similar results. Baddeley, Baddeley, Bucks, and Wilcock (2001) carried out two experiments investigating performance on different dual tasks. The tasks were carried out by healthy young and elderly participants as well as a group of AD patients. Their first experiment used a memory plus visuomotor dual task involving a digit recall task concurrently with a paper-and-pencil task in which participants had to mark crosses in a chain of boxes. Each task was carried out singly before being combined as the dual task. The results demonstrated no significant difference in dual task ability with age, but a significant decline in dual task performance by the AD patient group. Baddeley et al.'s (2001) second experiment comprised a complex visual search task and a test of auditory detection. The visual search task involved marking pictures of target objects in an array of distracter pictures, while the auditory detection task required participants to listen to a tape recording and repeat a target word immediately after it was heard. Again, participants carried out each task singly before moving on to the concurrent dual task. Baddeley et al. (2001) found no reliable dual task age effects between young and elderly healthy participants, and the results displayed a clear dual task performance decrement by the AD patients. The results of both experiments support the previous findings indicating a specific executive function for dividing attention, which appears to be damaged in Alzheimer's disease.

The dual task impairment has also been demonstrated using two memory tasks (MacPherson, Della Sala, Logie, & Wilcock, 2007). AD patients and healthy young and elderly controls were asked to perform a verbal memory digit recall task and a visuospatial memory visual patterns task, which involved being shown a random design of an equal number of black and white squares on a paper grid. The participants were shown the design for three seconds, after which the design was removed. The participants were then presented with a blank grid and were asked to cross the boxes that had been black squares in the design. The difficulty level of the visual patterns task was manipulated by altering the number of black squares in the grid, and could vary from 2 to 15 filled squares. The two tasks were titrated for individual ability level, and were carried out first as single tasks then simultaneously as the dual task. The results of the dual task showed no significant age effects between the healthy young and old participants, while the AD patients displayed a significant decrement in performance level compared to the healthy adults. The results therefore suggest that the dual task impairment previously found in memory plus visuomotor tasks also extends to the domain of memory plus memory dual tasks, when the tasks employed are carefully selected to draw separately upon the limited capacity storage systems in working memory (MacPherson et al., 2007).

1.3. When Are Dual Task Age Effects Found?

1.3.1. Increasing Task Difficulty

The dual task age differences between young and old healthy adults have been attributed to higher task demands during dual task compared with single task procedures, and depleting processing resources in healthy ageing. For example, Craik and McDowd (1987) had young and elderly healthy adults perform a cued recall or recognition memory task concurrently with a choice reaction time secondary task. The primary memory task involved learning a list of descriptive phrases and words under full attention; the phrases were then cued auditorily in the cued recall condition, and in the recognition condition the target words were presented auditorily along with distracter words. The secondary choice reaction time task involved pressing the appropriate key in response to the on-screen presentation of a target character, as quickly as possible, and was only carried out at the same time as the retrieval stage of the primary task. Craik and McDowd (1987) found significant effects of age on secondary task, with the older adults performing poorer than the young adults on the dual task. The results also showed that performance on the secondary task was worse during the cued recall condition than the recognition condition, particularly in the older adult age group. Craik and McDowd (1987) attribute these results to the greater processing resources required for cued recall compared to recognition, and believe that older adults have a smaller pool of processing resources to draw on than their younger counterparts. They thus argue that the age effects may highlight the fact that older adults find the dual task more difficult than young adults.

Naveh-Benjamin, Craik, Guez, & Kreuger (2005) found age effects in a dual task study, when memory performance was assessed using paired-associate learning and cued recall. The word pairs used were either semantically related or unrelated, and participants were either given specific instructions to help them encode the pairs or were not given any special instructions. The secondary task was a visuomotor tracking task. The results showed that older adults performed more poorly on the cued recall task compared to younger adults. The older group were poorer at recalling the more difficult unrelated pairs than related words, yet both age groups improved performance to the same extent when they used the instructed encoding strategy. Naveh-Benjamin et al. (2005) suggest that the older adults poor recall performance could be due to inefficient encoding strategies, potentially requiring a large amount of attentional resources. As the older adults may need to use much of their attentional resources on sustaining recall accuracy they may be unable to simultaneously attend to encoding strategies as successfully as the younger adults.

However, in the above mentioned studies the cued recall memory task involves encoding and retrieval strategies for accessing information in long term memory as opposed to assessing two tasks concurrently relying on working memory (MacPherson et al., 2007). It is also notable that the single tasks were not titrated for individual ability level, meaning that there could be baseline differences in single task ability between the young and elderly age groups leading to the dual task age effects (Della Sala, Foley, Beschin, Allerhand, & Logie, 2010; Salthouse, 1994).

In order to refute the possibility that the AD patients simply have increased sensitivity to task difficulty compared with healthy elderly controls which could account for the dual task results, Baddeley et al. (1991) asked participants from the Alzheimer's group and the elderly control group to undertake a categorisation task that was assessed over two sessions to give longitudinal data. The task involved categorising words as belonging to one, two, or four semantic categories as quickly as possible. The results showed that as expected the AD patients took longer when a greater number of categories were presented, and the control group were faster and more accurate than the patient group. The AD patients showed a drop in performance at the second testing session corresponding with the progression of the disease, however, there was no interaction between task difficulty and disease stage. This indicates that increasing the level of task difficulty does not make a task more sensitive to disease progression, and thus argues against any suggestion that AD patients performed poorer than controls on the dual task because they found the task more difficult, thereby offering support for the hypothesis of a specific central executive deficit in Alzheimer's patients (Baddeley et al., 1991).

A further investigation into task difficulty was carried out by Logie, Cocchini, Della Sala and Baddeley (2004) who varied the level of task demand in three experiments and compared the performances of healthy young and older adults and AD patients. The first experiment involved concurrent tracking and digit recall tasks. The participants carried out the dual task at an individually calibrated level as well as at a reduced load level. Logie et al. (2004) found that both high and low level loads resulted in dual task impairments, arguing against the suggestion that Alzheimer's patients perform poorly because dual tasking overloads their damaged attentional resource. Their second experiment was to compare single task performances between healthy young and elderly control groups as well as a group of AD patients. By repeatedly increasing the demand of the single task and finding a similar pattern of performance between the three groups, Logie et al. (2004) noted that patients with AD were not differentially impaired on difficult tasks when they were not required to divide their attention, arguing against such a hypothesis. In their third experiment, Logie et al. (2004) had the same participants as in experiment two carry out dual tasks where the level of demand in one task was held constant while the demand level of the second task was varied. The results showed that while both control groups and the patient group had decreased in performance as the task demand had increased, the AD patients were significantly impaired in their dual tasking ability. The experimental results also showed no interaction between the difficulty level and dual task performance, suggesting a specific dual task executive function separate from cognitive ability. The results of Logie et al.'s (2004) study argue against the hypothesis that dual task decrements seen in AD patients are due to increased sensitivity to the level of task difficulty, and support the suggestion of a specific dual task deficit in AD.

1.3.2. Measures of Reaction Time

Logie, Della Sala, MacPherson, & Cooper (2007) carried out a study using healthy young and elderly participants to assess the effects on memory of dual tasking during the encoding and retrieval phases. Their first dual task experiment comprised digit recall and a simple reaction time task involving pressing a key in response to the appearance of an asterisk in the centre of a computer screen. The reaction time task was carried out at both high and low speeds, and tasks were titrated for each participant. No significant difference was found between the young and elderly groups, indicating no significant effect of healthy ageing on overall dual task performance, however, when the effects of dual tasking were examined for encoding and retrieval phases of the tasks the data showed that dual tasking during encoding caused a greater decline in performance in the elderly participants than the young group. Logie et al. (2007) found a significant difference in reaction time between young and elderly adults for the secondary task, with the older adults performing significantly slower than younger participants, particularly during the retrieval phase of the dual task. Older adults were also found to react slower during the high speed condition of dual task at retrieval.

In their second experiment, the dual task comprised digit recall and a speeded choice reaction time task involving pressing the correct key in response to which side of the screen an asterisk appeared, as quickly and accurately as possible. The choice reaction time task was carried out at high and low demand levels; during the high demand condition the asterisk was presented randomly on the left or right of the screen, and during the low demand condition the asterisk was presented alternately on either side of the screen. Both the digit recall and reaction time tasks were individually calibrated. Logie et al. (2007) found a significant dual task decrement in performance on the digit recall task for both the young and elderly age groups when the two tasks were carried out simultaneously. There was found to be no effect of demand level of the reaction time task on the memory performance of both groups in encoding or retrieval conditions. However, reaction times were significantly slower for both age groups in the high demand condition of the dual task during the encoding phase. Older adults were found to perform the dual task slower than younger adults during both high and low demand conditions, although there were no significant age effects on error rates.

The age effects found in this study suggest that older adults may be disadvantaged during dual tasking compared to younger adults if performance on one of the concurrent tasks is measured by a timed response (MacPherson et al., 2007), despite single task performances being equated across groups. Logie et al. (2007) suggest that the lack of an age effect on error rates implies that older adults may make a trade-off between reaction time and accuracy, hence perform slower on tasks measured by response time in order to maintain a high level of accuracy.

1.3.3. Education Level

In many studies comparing the performance of young and elderly control groups against AD patients, the participants in the elderly group are age and education matched to the patient group (e.g. Baddeley et al., 1991) yet in only a few studies do young and elderly participants in the healthy control groups not differ significantly in years of formal education (MacPherson et al., 2007) or intelligence (Baddeley et al., 2001). Much of the research surrounding the dual task paradigm is carried out in universities and the young participant groups are often comprised of students attending the university and therefore have a high level of education. In comparison, elderly people making up the older age group and AD patient group grew up in a time when further education was not as accessible as it is today, and typically finished schooling at a much earlier stage in their lives. Baddeley et al. (1986) state that significant differences in years of formal education between young and elderly population groups "should be borne in mind in considering the performance of the young control group" (p. 82).

Haut et al. (2005) carried out an investigation into areas of brain activation in healthy young and old age groups with significantly different levels of education. An O^{15} [water] PET scan was carried out while participants completed a working memory task. The comparison groups were young adults with college education, elderly adults with college education, and elderly adults with only high school education. Haut et al. (2005) found different frontal lobe activation patterns in the two elderly groups, which varied with education level; older adults with a high level of education showed a peak of unilateral activation in the right posterior premotor cortex, while the less education older adults showed bilateral activation in the right posterior premotor cortex (at a significantly lower level than the well-educated older adults) and left prefrontal cortex. Both elderly groups performed the task to the same level, therefore Haut et al. (2005) suggest that the adults with the lower education level may have to recruit more cortical areas than the highly educated group in order to perform the task to the same ability. Alternatively, they suggest that the highly educated group may need less cortical activity than those with fewer years of education to be able to perform the task equally well as they can rely on storage processes, for example. A comparison of the young and elderly well-educated groups showed similar patterns of activation during the working memory task, with the younger participants displaying a greater level of activation in the left posterior parietal cortex suggestive of a greater dependence on information storage processes than the older highly educated participants. Although only carried out on a small sample size, the results of Haut et al.'s (2005) study showed different cognitive activation patterns during a working memory task in groups educated to different levels, and indicate the importance of taking into account the level of education between groups.

1.4. Dual Task Decrement is Specific to Dementia

There is a vast amount of literature refuting a dual task decrement in healthy ageing and supporting a dual task deficit in people with AD when tasks are titrated for individual ability and performance is equated across groups (e.g. Baddeley et al., 1986; Baddeley et al., 1991; Baddeley et al., 2001; Logie et al., 2004; MacPherson et al., 2007). There has also emerged a growing body of studies examining dual task ability in other disorders where episodic memory loss is a symptom, the findings from which indicate that dual task impairment is specific to dementia (e.g. Inasaridze, Foley, Logie, & Della Sala, 2010; Kaschel, Logie, Kazén, & Della Sala, 2009).

Adults with depression are one group of patients whose cognitive ability and episodic memory are affected by the disorder. With similarities in clinical test performance to early AD patients there is a risk of misdiagnosis, particularly in elderly adults (Kaschel et al., 2009). As dual task studies have indicated a particular deficit in concurrent task performance in AD patients but not in healthy ageing, Kaschel et al. (2009) compared the performance of AD patients, adults with chronic depression, and healthy elderly adults, matched in age and years of education, to investigate the pattern of dual task results. They predicted that the patients with chronic depression and the healthy elderly control group would not show a dual task deficit, but that the AD patients would display a performance decrement. A memory plus visuomotor dual task was employed using digit recall and a paper-and-pencil tracking task, which involved drawing a line through a path of circles. Single task performances were titrated to equate performance across groups, and the procedure was set up in such a way that participants carried out both single tasks, followed by two attempts at the dual task, and finally both single tasks. Single task performance scores were then averaged, as were the two dual task performance scores, to avoid practice or fatigue effects. Kaschel et al. (2009) found that the overall dual task scores indicated that the depressed group and the healthy elderly controls were not significantly different from one another, and were not impaired on the task, however the AD patient group were significantly impaired. This finding supports the suggestion of a dual task deficit in AD, even when compared against another population whose symptoms appear the same.

In order to assess the potential clinical contribution of dual tasking, Kaschel et al. (2009) carried out a second experiment comparing dual task performance between AD patients and depressed elderly adults who performed an episodic memory test at the same poor level of ability. Kaschel et al. (2009) hoped that the dual task scores would distinguish the two groups, unlike the traditional clinical test, as this would support the clinical use of dual tasking in the early assessment of AD when used alongside common test measures. The same dual task procedure was carried out as in their first experiment, using two new participant groups. The dual task results showed a significant impairment by the AD patients but not the depressed adults. As memory performance had been equated between the two groups Kaschel et al. (2009) concluded that dual tasking seems able to differentiate between AD and healthy ageing as well as AD and depression, therefore could provide a useful contribution in clinical assessments.

Vascular dementia (VaD) shares several dysexecutive symptoms with AD, therefore in order to investigate if the central executive coordination function is damaged in other forms of dementia, Inasaridze et al. (2010) evaluated the performance of VaD patients, and healthy young and elderly controls, on a memory plus visuomotor dual task with the expectation that VaD patients would be significantly impaired compared to healthy adults. The tasks involved digit recall and a paper-and-pencil tracking task, which required the participants to draw a line following a particular path around the paper. Both single tasks were titrated for individual ability level to equate performance across the groups. The results were as hypothesised; the VaD patient group showed a significant decrement in dual task performance in comparison with the healthy controls. Inasaridze et al. (2010) also compared the VaD group's performance against their Mini Mental State Exam (MMSE) score and found that ability on the dual task was significantly correlated with the severity of dementia. The results imply that the coordination function of the central executive is damaged specifically with the onset of dementia, and that tests of dual tasking could be used clinically to aid the diagnosis of dementia when applied alongside current measures.

1.5. The Development of Dual Tasking as a Clinical Tool

After the results of Baddeley (1986) and Baddeley et al.'s (1991) studies indicated a specific coordination function of the central executive, researchers began attempting to develop a dual task procedure that could be used clinically to indicate such functional damage (Baddeley, Della Sala, Gray, Papagno & Spinnler, 1997). Many of the original studies discussed above employed computerised tracking as the visuomotor tasks which were expensive and not easily transportable. Therefore the tasks were not suitable for daily use in a clinical setting. The aim to devise a paper-and-pencil task began with several attempts by Baddeley et al. (1997), who originally devised a pilot test with the visuomotor task based on the Fitts' Law paradigm (Fitts & Peterson, 1964); "the time taken to strike a target varied positively with the distance of the target and inversely with its width" (Baddeley et al., 1997, p. 66). Participants were given paper with two identical circles next to each other on the page, and using a pencil had to alternately tap inside the circles in time with a metronome. The size of the circles was gradually reduced to increase the difficulty level of the task. Digit recall was used as the memory task. However, Baddeley et al. (1997) found that healthy adults found the visuomotor tapping task very challenging even as a single task, and several stopped trying to keep in time with the metronome. When AD patients attempted the task a variety of problems arose; they too gave up trying to keep up to speed, several participants stopped to ask for further instructions, and some tapped the same circle repeatedly instead of alternating between the two. When the dual task was attempted numerous AD patients stopped tapping upon the presentation of the numbers, and others began to write the digits in the circles instead of tapping the circles and repeating the numbers.

Baddeley et al. (1997) thought that too heavy a load had been placed on the patient's decision-making capabilities by having to lift the pencil off of the paper, so their next paper-and-pencil task involved connecting dots through a maze pattern, without lifting the pencil from the paper. Several styles of mazes were created; the first had decreasing path widths but resulted in a high number of errors in the single task version, and was found too difficult in the dual task version. The second maze design involved a constant width and increasing maze complexity, however, Baddeley et al. (1997) found this design too straightforward for healthy adults, resulting in a ceiling effect. It was felt that mazes produced too many problems so were discarded in favour of crossing a chain of empty boxes connected with arrows. The arrows act as a visual instruction of which box to cross next, thus avoiding the problem of participants stopping to ask for further instructions. In 1995, Della Sala, Baddeley, Papagno, & Spinnler (as cited in Baddeley et al., 1997, p. 69) used the chain of boxes pencil-and-paper task along with digit recall to test dual task performance on a group of AD patients and controls. The results showed that as expected, the AD patients were significantly impaired on the dual task when compared against the control group. Baddeley et al. (1997) argue that this paper-and-pencil task has potential clinical use as it requires little training, is easy to produce and disseminate, and can be administered quickly. However, they accept that problems still exist. For example, although the digit recall task is individually titrated, the tracking task is not. Consequently, performance on the dual task cannot be measured by a single score, making it hard to compare one participant's performance against normative values.

To overcome these issues, Della Sala et al. (2010) published results using a modified version of the tracking task, comprising drawing a line through circles along a connected path. Again, digit recall was used as the memory task which was titrated for individual ability level. Each task performance was calculated as the proportional change in score between the single and dual task conditions, allowing an overall proportional performance score to be calculated, resulting in one final dual task performance score. Della Sala et al. (2010) tested 436 healthy adults aged 18-98, and ranging from 2-22 years of education, and found no significant differences in dual task ability. The test-retest results were high, making the dual task appropriate for clinical use in combination with episodic memory tests, to identify a deficit in the coordination function of the central executive, specific to dementia.

1.6. The Present Study

Although there are many benefits of a paper-and-pencil based task, the tracking task used above (Della Sala et al., 2010) cannot be calibrated to individual performance level, leaving open the possibility of single task differences. The present study employs the use of a tapping task using apparatus based on the Fitts' Law paradigm (Fitts & Peterson, 1964) combined with digit recall to comprise a memory plus visuomotor dual task. The benefit of the apparatus is that tapping performance can be individually titrated, as can the digit recall task, ensuring single task performance is equated across groups.

The objective of this study, therefore, is to trial the use of a small Fitts' Law Box as the visuomotor task in a dual task assessment, exploring age effects and determining its effectiveness and suitability as a clinical tool in the diagnosis of dementia. Two visuomotor tasks will be trialled; tapping in time with two alternately flashing lights (the Tapping (Flashing) condition), and tapping decreasing target disc sizes (the Tapping (Disc) condition). An age effect is expected on the timed Tapping (Flashing) condition as it is a measure of reaction time (see Logie et al., 2007). No age effect is predicted for the Tapping (Disc) condition. Both conditions are being tested to explore the most suitable condition for titration of the single tasks in order to avoid age effects thus replicating the computerised visuomotor tasks.

2. Method

2.1. Participants

Fifty people participated in this study. This consisted of 25 healthy older adults and 25 healthy younger adults.

The 25 healthy older adults (17 females, 68%) ranged in age from 65 to 90 years (mean = 78.56, SD = 7.37), and in formal education from 11 to 17 years (mean = 13.16, SD = 1.84). They were recruited through the Participant Panel at the University of Edinburgh, and opportunistically through contacts of the researcher.

The 25 healthy younger adults (21 females, 84%) ranged in age from 20 to 29 years (mean = 23.60, SD = 2.10), and in formal education from 15 to 18 years (mean = 17.12, SD = 0.88). They were recruited opportunistically through contacts of the researcher.

All participants were native English speakers, and all had normal or corrected-to-normal vision. No participant had a reported history of hearing problems, neurological disorders or motor impairments. Recruitment was achieved by telephone, e-mail and word-of-mouth. This study was approved by the Lothian Research Ethics Committee and the University of Edinburgh's School of Philosophy, Psychology and Language Sciences Research Ethics Committee.

2.2. Design

A 2 x 2 x 3 (group x condition x task) between-subjects repeated measures design was planned. This resulted in Single Task, Dual Task and Overall Dual Task measures for the young and elderly groups on both the Tapping (Flashing) and the Tapping (Disc) conditions.

2.3. Materials and Assessments

2.3.1. Dual Task

2.3.1.1. Establishing the Digit Span

To ascertain the participant's Digit Span, a list of digits was played aloud using a Dell Inspiron 1545 laptop computer with built-in speakers. Digit Span presentations were created using Microsoft Office Powerpoint 2007 software. All presentations were digitally recorded by a female native English speaker at a rate of one digit per second. Beginning with three-digit lists, the participant was played the recording and asked to recall the list immediately. If the participant correctly recalled three out of five trials, the list increased by one digit. The participant's Digit Span was established as the maximum length at which they could correctly recall three out of five lists.

2.3.1.2. Establishing the Tapping (Flashing) Span

The tapping task was carried out using a specially designed Fitts' Law Box (Figure 3) which allowed calibration of each participant's Tapping (Flashing) Span and Tapping (Disc) Span. The participants held the attached stylus and tapped two metal discs alternately in time with a small flashing light above each disc. A control panel connected to the Fitts' Law Box allowed the time, flashing rate and disc size to be set manually by the researcher; tapping accuracy was electronically recorded and displayed as a percentage on the control panel screen at the end of each trial. To determine the participant's Tapping (Flashing) Span, the apparatus was set up using disc size 2 (the second largest; 20.7 mm) with the flashing rate set at 0.8 seconds, and time set for 10 seconds. The participant was instructed to accurately tap the two metal discs in time with two alternately flashing lights; one above each disc. If the participant scored greater than or equal to 90% on three out of five trials, the flashing rate was decreased by 0.1 second resulting in the lights flashing faster. If the participant failed to score greater than or equal to 90% on three out of five trials at the first rate, the flashing speed was increased by 0.1 second causing the lights to flash slower. The participant's Tapping (Flashing) Span was accepted as the quickest rate that they achieved greater than or equal to 90% on three out of five trials.

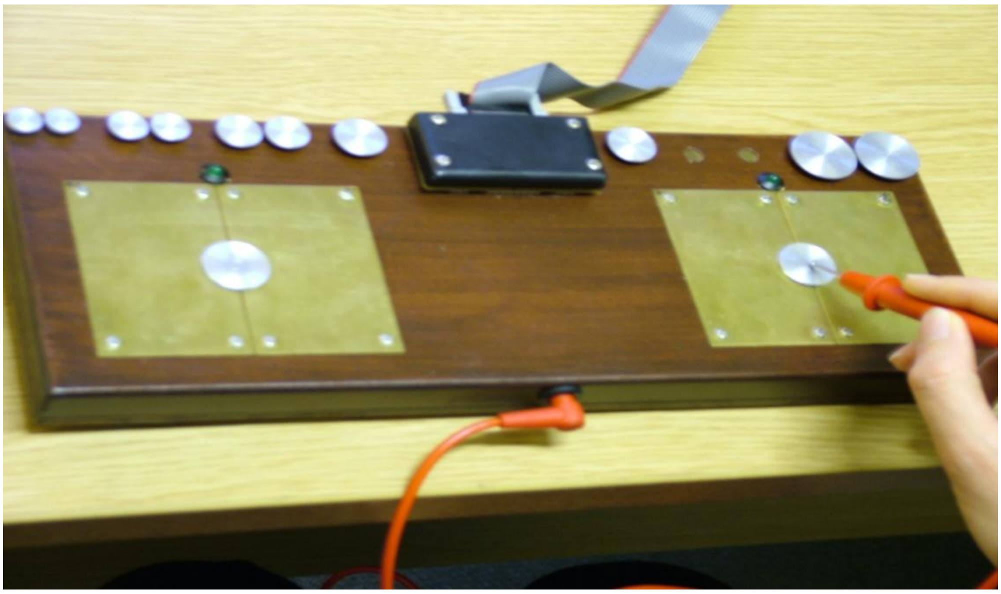

Figure 3. Photograph displaying the Fitts' Law Box.

2.3.1.3. Establishing the Tapping (Disc) Span

The apparatus was set up using disc size 2, with the flashing rate set at the participant's Tapping (Flashing) Span + 0.1 second, and time set for 10 seconds. The participant was again instructed to accurately tap the two metal discs in time with the alternately flashing lights. If the participant scored greater than or equal to 90% on three out of five trials, the disc size was decreased (17.3 mm; 14.4 mm; 12 mm; 10 mm). If the participant failed to score greater than or equal to 90% on three out of five trials using disc size 2, the disc size was increased (24.9 mm). The participant's Tapping (Disc) Span was accepted as the smallest disc size that they achieved greater than or equal to 90% on three out of five trials.

2.3.1.4. Digit Recall Single Task

The computer was set up to play the Digit Span Powerpoint Presentations. The appropriate Single Task span presentation was selected for the participant corresponding to their Digit Span. The task lasted one minute, and was timed using a stopwatch. The participant was asked to listen carefully and repeat the lists, which would always be the length of their Digit Span. Responses were recorded on the scoresheet and then the next list was played. The participant's Digit Recall Single Task score was calculated as the percentage of accurately recalled digits, in correct serial order, from the total number of digits heard across all lists.

2.3.1.5. Tapping (Flashing) Single Task

The apparatus was set up using disc size 2, with the flashing rate set to the participant's Tapping (Flashing) Span, and time set for one minute. The participant was instructed to accurately tap the two discs in time with the alternately flashing lights. The Tapping (Flashing) Single Task score was displayed as percentage accuracy on the control panel of the dual task apparatus at the end of the timed period.

2.3.1.6. Tapping (Disc) Single Task

The apparatus was set up using disc sizes of the participant's Tapping (Disc) Span, with the flashing rate set to their Tapping (Flashing) Span rate + 0.1 second, and the time set for one minute. The participant was instructed to accurately tap the discs in time with the alternately flashing lights. The Tapping (Disc) Single Task score was displayed as percentage accuracy on the control panel of the apparatus at the end of the timed period.

2.3.1.7. Digit Recall + Tapping (Flashing) Dual Task

The apparatus was set up using disc size 2, with the flashing rate set to the participant's Tapping (Flashing) Span, and the time set for 70 seconds. The computer was set up to play the Dual Task version of the Powerpoint Presentation corresponding to the participant's Digit Span. The participant was asked to accurately tap the discs in time with the alternately flashing lights and at the same time repeat the digit sequences which would always be the length of their Digit Span. The tapping task began 10 seconds prior to the first digit sequence being presented to allow the participant to get into the rhythm of the lights; therefore the Dual Task lasted one minute. Responses to the digit sequences were recorded on the scoresheet, and then the next list was played. The Digit Recall Dual Task score was recorded as the percentage of accurately recalled digits, in correct serial order, from the total number of digits heard across all lists, while the Tapping (Flashing) Dual Task score was displayed as percentage accuracy on the control panel of the apparatus at the end of the timed period.
The overall Dual Task performance for Digit Recall + Tapping (Flashing) was calculated as a percentage as follows:

$$100 - \frac{(Single\ Task - Dual\ Task)\ \times 100}{Single\ Task}$$

for both Digit Recall and Tapping (Flashing) performances, and then finding the average of these scores.

2.3.1.8. Digit Recall + Tapping (Disc) Dual Task

The apparatus was set up using the disc size of the participant's Tapping (Disc) Span, with the flashing rate set to their Tapping (Flashing) Span + 0.1 second, and the time set for 70 seconds. The computer was set up to play the Dual Task version of the Powerpoint Presentation corresponding to the participant's Digit Span. The participant was asked to accurately tap the discs in time with the alternately flashing lights and at the same time repeat the digit sequences which would always be the length of their Digit Span. The tapping task began 10 seconds prior to the first digit sequence being presented to allow the participant to get into the rhythm of the lights; therefore the Dual Task lasted one minute. Responses to the digit sequences were recorded on the scoresheet, and then the next list was played. The Digit Recall Dual Task score was recorded as the percentage of accurately recalled digits, in correct serial order, from the total number of digits heard across all lists, while the Tapping (Disc) Dual Task score was displayed as percentage accuracy on the control panel of the apparatus at the end of the timed period. The overall Dual Task performance for Digit Recall + Tapping (Disc) was calculated as a percentage as follows:

$$100 - \frac{(Single\ Task - Dual\ Task)\ \times 100}{Single\ Task}$$

for both Digit Recall and Tapping (Disc) performances, and then finding the average of these scores.

2.3.2. Cognitive and Neuropsychological Tests

2.3.2.1. Cognitive Screening

The Addenbrooke's Cognitive Examination – Revised (ACE-R; Mioshi et al., 2006) was administered to all participants to provide an indication of general cognitive functioning. Scores are out of 100, with scores less than 88 considered to be indicative of global cognitive decline.

2.3.2.2. Tests of Executive Function

2.3.2.2.1. Verbal Fluency (F A S)

The participant was asked to orally list as many words as possible in 60 seconds, beginning with the specified letter. Proper nouns, numbers and the same word with a different suffix were excluded, and the letters F, A, and S were each used. This test provides a measure of ability of word production under search constraints (Strauss, Sherman & Spreen, 2006).

2.3.2.2.2. Similarities

The Similarities subtest from the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) is a measure of verbal comprehension. The participant was asked to verbally explain the similarities between pairs of objects or concepts, which become progressively more abstract throughout the list of 19 pairs. Questioning began on pair 6, and if a score of 2 was not obtained then reverse administration of pairs 1 to 5 was carried out. The test was discontinued after the final pair or after 4 consecutive scores of 0. Scores are out of a total of 33.

2.3.2.2.3. Trail Making Test A & B

The Trail Making Test (TMT; Army Individual Test Battery, 1944) provides a measure of mental flexibility, speed and attention (Strauss et al., 2006) and is comprised of two parts; A and B. For TMT-A, the participant was asked to connect 25 numbered circles in ascending order. The participant was then asked to connect 25 encircled numbers and letters alternately in ascending order for TMT-B. For each test, the participant was directed to use a pencil to connect the circles as quickly as possible without lifting the pencil off the paper. Errors were pointed out by the assessor and corrected immediately so that scoring was based on completion time alone (Reitan, 1958).

2.3.2.3. Tests of Memory

2.3.2.3.1. People Test

The People subtest from the Doors and People test (Baddeley, Emslie & Nimmo-Smith, 1994) tests immediate and delayed verbal recall. The participant was shown pictures of four people with their name and occupation printed below, and was asked to learn the names and paired occupation. Recall was tested immediately, and after a delay of 10 minutes. Scores are out of 36 for the immediate recall subtest, and out of 12 for the delayed recall subtest.

2.3.2.3.2. Shapes Test

The Shapes subtest from the Doors and People test (Baddeley et al., 1994) assesses immediate and delayed visual recall. The participant copied pictures of four simple shapes before being asked to draw them from memory immediately, and after a delay 10 minutes. Scores are out of 36 for the immediate recall subtest, and out of 12 for the delayed recall subtest.

2.4. Procedure

Participants were asked to read an information sheet (see Appendix A) regarding the study prior to testing. Any questions were answered, and participants were then asked to sign a consent form (see Appendix B) confirming informed consent and acknowledging their right to terminate testing at any stage with no consequences to themselves. All participants completed the Dual Task first, and Spans were established in the order of Digit Span, Tapping (Flashing) Span, and then Tapping (Disc) Span. The order of the remaining subtasks was counterbalanced between each group to prevent practice and fatigue effects. The People and Shapes Immediate Recall subtests from the Doors and People test (Baddeley et al., 1994) were then administered, followed by the remaining cognitive and neuropsychological tests in a randomised order. The People and Shapes Delayed Recall subtests (Baddeley et al., 1994) were administered last.

3. Results

One participant in the elderly group scored below the cut-off of 88 on the ACE-R (Mioshi et al., 2006) indicating general cognitive impairment so all data pertaining to this participant was removed from further analyses.

The statistical analyses were carried out using PASW (SPSS) version 17. For each of the variables, means and standard deviations were calculated. The Kolmogorov-Smirnov test was used to assess normality of distribution and, if significant, the z-scores for skewness and kurtosis were examined. The Levene's test was used to assess homogeneity of variance. These results are reported only where the assumptions of normality and homogeneity are violated.

3.1. Participant Characteristics

Years of education, and general cognitive functioning as measured with the ACE-R (Mioshi et al., 2006), were examined in order to check for group differences other than age. The results of a Kolmogorov-Smirnov test indicated that the distribution of years of education was not normal in the two groups (D (49) = 0.20, $p < 0.001$). The Levene's test of homogeneity of variance indicated that equal variances could not be assumed between the two groups for years of education (F (1, 47) = 6.93, $p < 0.05$). A Mann-Whitney test identified that the young group had significantly greater years of education than the elderly group (U = 29.00, $p < 0.001$, r = 0.79).

ACE-R (Mioshi et al., 2006) scores were not normally distributed between the two groups (D (49) = 0.24, $p < 0.001$), with a significantly negatively skewed ($z_{skewness} = -9.06$) and leptokurtic ($z_{kurtosis} = 4.64$) score distribution in the young participant group. A Levene's test indicated insufficient homogeneity of variance between the two groups (F (1, 47) = 7.30, $p < 0.05$). A Mann-Whitney test identified a significant difference in ACE-R (Mioshi et al., 2006) score between the young and elderly group (U = 63.50, $p < 0.001$, r = 0.69).

3.2. Dual Task Performance

Group performances on all single and dual tasks are shown in Table 1.

Table 1. Summary of mean Dual Task scores and standard deviations for each age group.

		Young Mean (SD)	Elderly Mean (SD)
	Digit Span	6.48 (0.92)	5.08 (1.01)
Single Task	Tapping (Flashing)	91.58 (6.83)	80.90 (10.96)
	Tapping (Disc)	94.96 (5.83)	83.17 (11.17)
	Digit Recall	96.48 (4.39)	88.68 (10.07)
Dual Task	Tapping (Flashing)	97.54 (9.43)	80.36 (9.84)
	Digit Recall (Flashing)	99.85 (9.12)	82.85 (15.55)
	Tapping (Disc)	96.41 (5.89)	83.11 (9.64)
	Digit Recall (Disc)	102.64 (5.82)	81.88 (15.15)
Overall Dual Task	Tapping (Flashing)	98.70 (8.04)	81.54 (10.92)
	Tapping (Disc)	99.52 (4.71)	82.50 (10.09)

Digit Span was not normally distributed (D (49) = 0.16, $p < 0.01$) in the two age groups. A Mann-Whitney test revealed a significant difference between the groups; the younger participants had a longer Digit Span than the older adults (U = 95.50, $p < 0.001$, r = 0.60).

Single Task Digit Recall was not normally distributed (D (49) = 0.21, $p < 0.001$). Equal variances could not be assumed for the two groups (F (1, 47) = 16.82, $p < 0.001$), and a Mann-Whitney test showed that the younger participants performed significantly better than the elderly group (U = 165.00, p = < 0.01, r = 0.40) on the Digit Recall Single Task.

The Tapping (Flashing) Single Task data was not normally distributed (D (49) = 0.16, $p <$ 0.01), and was significantly negatively skewed ($z_{skewness}$ = -3.43) in the young group. The data also violated the assumption of homogeneity of variance (F (1, 47) = 10.12, $p < 0.01$). A Mann-Whitney test indicated that the younger group had a significantly higher score than the elderly group (U = 130.00, $p < 0.01$, r = 0.49) on the Tapping (Flashing) Single Task.

The data for the Tapping (Disc) Single Task was not normally distributed (*D* (49) = 0.17, $p < 0.01$), and was significantly negatively skewed ($z_{skewness} = -4.45$) in the young adult group. There was insufficient homogeneity of variance between the two age groups (F (1, 47) = 9.54, $p < 0.01$). A significant difference was found between the groups, with the younger group scoring higher than the elderly group ($U = 108.00$, $p < 0.001$, $r = 0.55$).

In the Dual Task Tapping (Flashing) condition, the data for the concurrent Digit Recall task violated the assumption of homogeneity of variance (F (1, 47) = 5.30, $p < 0.05$). A significant group difference was found between young and elderly participants, with the young group outperforming the older adults ($U = 88.50$, $p < 0.001$, $r = 0.61$) on the Digit Recall portion of the task.

The Tapping (Flashing) task carried out simultaneously with Digit Recall resulted in Tapping scores which were not normally distributed (*D* (49) = 0.16, $p < 0.01$). The data for the young group was significantly positively skewed ($z_{skewness} = 5.31$) and leptokurtic ($z_{kurtosis} = 3.14$). A significant difference was revealed between the two groups; the younger adults scored higher on the Tapping (Flashing) part of the Dual Task than the elderly participants ($U = 25.00$, $p < 0.001$, $r = 0.79$).

In the Dual Task Tapping (Disc) condition, the data for the concurrent Digit Recall task was not normally distributed (*D* (49) = 0.24, $p < 0.001$), and equal variances could not be assumed for the young and elderly groups (F (1, 47) = 10.75, $p < 0.01$). The young group performed significantly better on the Digit Recall part of the Dual Task than the older adults ($U = 50.50$, $p < 0.001$, $r = 0.73$).

The Tapping (Disc) task carried out simultaneously with Digit Recall gave rise to Tapping scores which were not normally distributed (*D* (49) = 0.15, $p < 0.05$), and significantly negatively skewed ($z_{skewness} = -2.86$) for the young participants. The data also violated the assumption of homogeneity of variances (F (1, 49) = 12.63), $p < 0.01$). There was found to be a significant difference between the age groups, with the young group performing the Tapping (Disc) part of the Dual Task more accurately than the elderly group ($U = 50.00$, $p < 0.001$, $r = 0.71$).

An independent *t*-test revealed a significant difference in Overall Tapping (Flashing) Dual Task score between the young and elderly participants (t (47) = 6.28, p < 0.001), with the young participants scoring higher than the older adults.

The data in the Overall Tapping (Disc) Dual Task condition was not normally distributed (D (49) = 0.15, p < 0.01). There was insufficient homogeneity of variance between the two groups (F (1, 47) = 16.36, p < 0.001). A significant difference in Overall Tapping (Disc) Dual Task performance was found between the young and elderly groups (U = 38.00, p < 0.001, r = 0.75), with the young participants scoring higher than the older adults.

3.3. Cognitive and Neuropsychological Test Performance

Group performances on all cognitive and neuropsychological tests assessing executive functioning and memory are displayed in Table 2.

Table 2. Summary of mean memory and executive function test scores and standard deviations for each age group.

	Young Mean (SD)	Elderly Mean (SD)
Verbal Fluency	62.92 (9.63)	42.00 (14.18)
Similarities	28.60 (2.04)	23.42 (2.62)
Trail Making Test	2.23 (0.43)	1.98 (0.25)
People (Immediate Recall)	33.68 (2.25)	23.17 (5.67)
People (Delayed Recall)	17.12 (10.60)	7.63 (2.67)
Shapes (Immediate Recall)	29.44 (10.58)	29.33 (4.88)
Shapes (Delayed Recall)	11.80 (0.41)	9.08 (1.44)

An independent samples *t*-test indicated that there was a significant group difference on the Verbal Fluency test (t (47) = 6.06, p < 0.001). The young participants scored significantly higher than the older adults.

There was also a significant difference between the two age groups on the Similarities test, with the younger adults scoring higher than the elderly group (t (47) = 7.74, p < 0.001).

The data for the TMT was not normally distributed (D (49) = 0.18, $p < 0.001$), and violated the assumption of homogeneity of variance between the two groups (F (1, 47) = 7.11, $p < 0.05$). The results of a Mann-Whitney test revealed that the young adults scored significantly higher than the older adults (U = 183.00, $p < 0.05$, r = 0.33) on the TMT.

The scores from the People (Immediate Recall) subtest from the Doors and People test (Baddeley et al., 1994) were not normally distributed between the groups (D (49) = 0.16, $p < 0.01$). There was also insufficient homogeneity of variance between the two age groups (F (1, 47) = 14.86, $p < 0.001$). The young group performed significantly better than the elderly group on the People (Immediate Recall) test (U = 12.00, $p < 0.001$, r = 0.83).

Likewise, the scores from the People (Delayed Recall) test were not normally distributed (D (49) = 0.40, $p < 0.01$), with a significantly positively skewed ($z_{\text{skewness}} = 2.75$) distribution of scores in the young participant group. Equal variances could not be assumed for the two age groups (F (1, 47) = 32.22, $p < 0.001$). The younger adults scored significantly higher than the older adults on the People (Delayed Recall) test (U = 36.00, $p < 0.001$, r = 0.77).

The scores from the Shapes (Immediate Recall) subtest from the Doors and People test (Baddeley et al., 1994) were not normally distributed between the groups (D (49) = 0.22, $p < 0.001$). The young participant group showed a significantly negatively skewed ($z_{\text{skewness}} = -2.60$) score distribution. The data violated the assumption of homogeneity of variance between the participant groups (F (1, 47) = 16.67, $p < 0.001$). There was a significant difference in scores on the Shapes (Immediate Recall) test between the two age groups (U = 191.50, $p < 0.05$, r = 0.31), with the young group scoring higher than the elderly group.

The scores from the Shapes (Delayed Recall) test were not normally distributed (D (49) = 0.24, $p < 0.001$), with a significantly negatively skewed ($z_{\text{skewness}} = -3.44$) distribution of scores in the young participant group. There was insufficient homogeneity of variance between the age groups (F (1, 47) = 8.61, $p < 0.01$). The younger adults scored significantly higher than the older adults on the Shapes (Delayed Recall) test (U = 25.00, $p < 0.001$, r = 0.83).

3.4. Relationships with Dual Task Performance

3.4.1. Tapping (Flashing) Dual Task

The Dual Task performance of the Tapping (Flashing) task was significantly positively correlated with years of education ($\rho = 0.60$, $p < 0.001$). Similarly, the concurrent Digit Recall task was significantly positively correlated with years of education ($\rho = 0.44$, $p < 0.01$). Overall Tapping (Flashing) Dual Task performance was also significantly positively correlated with years of education ($r = 0.56$, $p < 0.001$) implying that Dual Task performance improved with increasing years of education.

The Dual Task performance of the Tapping (Flashing) task was significantly positively correlated with ACE-R (Mioshi et al., 2006) score ($\rho = 0.72$, $p < 0.001$), as was the simultaneous Digit Recall task ($\rho = 0.57$, $p < 0.001$). Overall Tapping (Flashing) Dual Task performance was significantly positively correlated with general cognitive functioning ($r = 0.62$, $p < 0.001$) indicating that Tapping (Flashing) Dual Task performance increased with increasing ACE-R (Mioshi et al., 2006) score.

In terms of the tests of executive function and memory, the Dual Task performance of the concurrent Tapping (Flashing) task was significantly positively correlated with the measures of Verbal Fluency ($\rho = 0.68$, $p < 0.001$), Similarities ($\rho = 0.64$, $p < 0.001$), People (Immediate Recall, $\rho = 0.76$, $p < 0.001$; Delayed Recall, $\rho = 0.70$, $p < 0.001$) and Shapes (Immediate Recall, $\rho = 0.30$, $p < 0.05$; Delayed Recall, $\rho = 0.65$, $p < 0.001$) suggesting that Tapping (Flashing) performance increased with increasing executive function and memory ability.

The Dual Task performance of the concurrent Digit Recall task was significantly positively correlated with the executive function measures of Verbal Fluency ($\rho = 0.57$, $p < 0.001$), Similarities ($\rho = 0.51$, $p < 0.001$), and with the memory measure of People (Immediate Recall, $\rho = 0.62$, $p < 0.001$; Delayed Recall, $\rho = 0.64$, $p < 0.001$) and Shapes (Immediate Recall, $\rho = 0.30$, $p < 0.05$; Delayed Recall, $\rho = 0.58$, $p < 0.001$) implying that Digit Recall performance increased with increasing executive function and memory ability.

Overall Tapping (Flashing) Dual Task performance was significantly positively correlated with the executive function assessments of Verbal Fluency ($r = 0.63$, $p < 0.001$), and Similarities ($r = 0.57$, $p < 0.001$), and significantly positively correlated with the memory assessments of People (Immediate Recall, $r = 0.69$, $p < 0.001$; Delayed Recall, $r = 0.51$, $p < 0.001$) and Shapes (Delayed Recall, $r = 0.66$, $p < 0.001$) indicating that Overall Tapping (Flashing) Dual Task performance increased as scores on these assessments increased.

3.4.2. Tapping (Disc) Dual Task

The Dual Task performance of the Tapping (Disc) task was significantly positively correlated with years of education ($\rho = 0.62$, $p < 0.001$). Similarly, the concurrent Digit Recall task was significantly positively correlated with years of education ($\rho = 0.55$, $p < 0.001$). Overall Tapping (Disc) Dual Task performance was also significantly positively correlated with years of education ($\rho = 0.57$, $p < 0.001$) implying that Dual Task performance improved with increasing years of education.

The Dual Task performance of the Tapping (Disc) task was significantly positively correlated with ACE-R (Mioshi et al., 2006) score ($\rho = 0.63$, $p < 0.001$), as was the simultaneous Digit Recall task ($\rho = 0.54$, $p < 0.001$). Overall Tapping (Disc) Dual Task performance was significantly positively correlated with general cognitive functioning ($\rho = 0.57$, $p < 0.001$) indicating that Tapping (Disc) Dual Task performance increased with increasing ACE-R (Mioshi et al., 2006) score.

In terms of the tests of executive function and memory, the Dual Task performance of the concurrent Tapping (Disc) task was significantly positively correlated with the measures of Verbal Fluency ($\rho = 0.62$, $p < 0.001$), Similarities ($\rho = 0.61$, $p < 0.001$), People (Immediate Recall, $\rho = 0.75$, $p < 0.001$; Delayed Recall, $\rho = 0.67$, $p < 0.001$) and Shapes (Immediate Recall, $\rho = 0.29$, $p < 0.05$; Delayed Recall, $\rho = 0.59$, $p < 0.001$) suggesting that Tapping (Disc) performance increased with increasing executive function and memory ability.

The Dual Task performance of the concurrent Digit Recall task was significantly positively correlated with the executive function measures of Verbal Fluency ($\rho = 0.67$, $p < 0.001$), Similarities ($\rho = 0.57$, $p < 0.001$), and with the memory measure of People (Immediate Recall, $\rho = 0.71$, $p < 0.001$; Delayed Recall, $\rho = 0.72$, $p < 0.001$) and Shapes (Immediate Recall, $\rho = 0.35$, $p < 0.05$; Delayed Recall, $\rho = 0.65$, $p < 0.001$) implying that Digit Recall performance increased with increasing executive function and memory ability.

Overall Tapping (Disc) Dual Task performance was significantly positively correlated with the executive function assessments of Verbal Fluency ($\rho = 0.67$, $p < 0.001$), and Similarities ($\rho = 0.58$, $p < 0.001$), and significantly positively correlated with the memory assessments of People (Immediate Recall, $\rho = 0.74$, $p < 0.001$; Delayed Recall, $\rho = 0.72$, $p < 0.001$) and Shapes (Immediate Recall, $\rho = 0.35$, $p < 0.05$; Delayed Recall, $\rho = 0.63$, $p < 0.001$) indicating that Overall Tapping (Disc) Dual Task performance increased as scores on these assessments increased.

4. Discussion

The aim of this study was to test a Fitts' Law Box as the visuomotor task in a dual task assessment. Age effects were explored to establish the equipment's effectiveness and suitability as a clinical tool in the diagnosis of dementia. This was examined through two memory plus visuomotor dual tasks, which were performed by a group of healthy young adults and a healthy elderly participant group.

4.1. Discussion of Results

The results confirmed the predicted age effect on the Tapping (Flashing) Dual Task condition. An age effect was also found on the Tapping (Disc) Dual Task condition. It is notable that the young participant group performed significantly better than the older adult group on all Tapping and Digit Recall components of the dual task paradigm, and the single tasks. These findings show that neither condition successfully managed to avoid significant age difference in the task results for the participant groups in this study, thus cast doubt on the effectiveness of the Fitts' Law Box as the visuomotor task in a dual task assessment.

As predicted, there was a significant difference between the young and elderly groups on Dual Task Tapping (Flashing) performance despite the two tasks being titrated for individual performance, as the Tapping (Flashing) task was a measure of reaction time (Logie et al., 2007). The age effect found on the Tapping (Disc) Dual Task was unexpected, and there were also significant group differences on the two Digit Recall Dual Tasks after individual calibration on single task performances. These findings are not consistent with the results of previous dual task studies which found no age effects between healthy young and elderly adults (Baddeley et al., 2001; Baddeley et al., 1986; MacPherson et al., 2007). The same or similar single task titration techniques have been used successfully in previous studies (e.g. Baddeley et al., 1997; Della Sala et al., 2010; Inasaridze et al., 2010; Logie et al., 2004) where no age differences in Overall Dual Task scores were found, implying the calibration method did not give rise to the differences. One possible explanation for the difference in findings on the Tapping (Disc) task could be to argue that the task involved a speeded component, like the Tapping (Flashing) task. In the calibration process of the Tapping (Disc)

Single Task condition the participants were required to tap the discs in time with the alternately flashing lights, which were set to flash at a constant rate. This meant the participants had to tap a disc as soon as the light above it flashed, and before the light above the other disc flashed. Thus participants had to react quickly or consequently they would be out of time with the flashing rate, resulting in a poor score. In the paper-and-pencil box crossing visuomotor task used in the Della Sala et al. (2010) study, participants were instructed to “draw a line through each successive circle as quickly as they could” (p. 3), and in the computerised tracking tasks used by Baddeley et al. (1986) and MacPherson et al. (2007) participants were asked to maintain a light-pen over a moving target. Although these tasks as a whole were carried out for a specified amount of time (e.g. 90 seconds in the box crossing task), they did not involve the same level of time pressure to respond as was the case with the flashing lights in the Tapping (Disc) task, and no significant effect of age was found in these studies. If the Tapping (Disc) task was considered to involve responding under pressure of time, age differences between young and elderly groups of healthy adults would be expected (Logie et al., 2007; MacPherson et al., 2007).

Despite the above possible explanation for the finding of an age effect in the Tapping (Disc) Dual Task, the fact remains that a significant difference in the concurrent Digit Recall task was also found between the young and older adult participants, as was an age effect in the Digit Recall task carried out simultaneously with the Tapping (Flashing) task. An explanation that may account for these Digit Recall age effects is that the baseline differences in abilities between the groups were too great; there was a significant age difference in ACE-R (Mioshi et al., 2006) score, which was also significantly positively correlated with each measure of the two dual task conditions as well as the Overall Dual Task scores. This implies that participants with higher scores on the measure of cognitive functioning performed better on the dual tasks than those with lower scores. The age differences show that the younger participants scored significantly higher on the ACE-R (Mioshi et al., 2006) than the older adults. In addition there were significant positive correlations between years of education and the tasks employed in both Tapping (Flashing) and concurrent Digit Recall, and Tapping (Disc) and simultaneous Digit Recall. This indicates that the participants with more years of education performed the task better than those with fewer years of education. The younger participants had significantly more years of education than the elderly group as they were all current university students or recent graduates, whereas the elderly group comprised few participants who had studied beyond high school.

Perfect and Maylor (2000) proposed the dull hypothesis of cognitive ageing. They argue that rather than rejecting a null hypothesis of no difference between young and elderly populations, studies of cognitive ageing should reject the *dull* hypothesis of young adults performing better than older adults on every type of task. However, the correlations between cognitive function as measured by the ACE-R (Mioshi et al., 2006) and the visuomotor single and dual tasks have been suggested to indicate that "cognitive and motor performances may be impaired by the same pathological processes" (Camicioli, Howieson, Lehman & Kaye, 1997, p. 957). As the assessments of memory, executive function, and motor ability were all performed significantly more poorly by the elderly participants in this study, the dull hypothesis cannot be rejected. The results are instead suggestive of global slowing with age, offering support to theorists such as Salthouse (1985) who argues that age differences arise due to individual variances in information processing speed.

Termed the processing rate theory of cognitive ageing, Salthouse's (1985) theory proposes that ageing causes a decline in the rate at which cognitive operations are carried out. This directly affects the quality and quantity of cognitive performance in a variety of tasks. Although it is accepted that other factors also affect cognitive performance, this slowing is argued to be the main cause, and thus the reason why older adults perform more poorly than younger adults on a range of tasks. An example from the current dual task study can be gained by discussing the Digit Recall tasks. To begin with, the older adults had a significantly lower Digit Span compared to the younger adults. They therefore heard lists containing fewer digits than the younger group in the Digit Recall tasks. It was noted that after hearing each list, the participants in the young group tended to quickly recall the digits as soon as the last digit in the list had been heard, whereas the older adults tended to pause before repeating the digits slowly and deliberately, possibly because they had processed the information slower than the young adults (Salthouse, 1985). For both groups, the next list was played as soon as recall of the previous list was completed. The overall scores were computed by calculating the percentage of correctly recalled digits from the total number heard within one minute, and as the younger adults heard more digits, and recalled them with greater accuracy than the elderly group, they consequently had a significantly higher score than the older adults. Although Woodruff-Pak (1997) argues that significant age differences in digit recall between healthy young and elderly groups are unlikely to be found because the skill is highly practiced and used frequently in everyday life, for example when reciting a telephone number or when entering a PIN number, Salthouse's (1985) theory counters that.

He argues that the reason for the older adults having a shorter Digit Span, and carrying out the Digit Recall tasks at a slower rate than the young adults, is because the relevant cognitive operations needed to carry out the tasks have slowed with age, resulting in the significantly poorer performance by the older adult group than the young group.

Salthouse (1985) also argues that in older adults, previously efficient processing strategies may no longer be as effective as they once were, as a result of the slowing of cognitive operations. He suggests that this may result in less efficient strategies having to be used. An example of this is gleaned from the Verbal Fluency component of the ACE-R (Mioshi et al., 2006), which required participants to name as many animals as they could, beginning with any letter, in the space of one minute. The most successful way to carry out this task is to cluster animals into subcategories of semantic or phonological similarity, and once that list has been exhausted switch to the next cluster (Troyer, Moscovitch, & Winocur, 1997). This is exactly what all of the young participants did, as well as most of the elderly group; either by clustering by categories such as zoo animals, farm animals, pets, insects, sea creatures etc., or by naming as many animals as they could that began with the letter A, then B, then C and so on. These were both successful strategies, resulting in a reasonably long list of words produced within the time limit. However, a few older adults used a far less effective alphabet strategy. These participants began with the letter A, but only named one animal. They then named one animal beginning with B, one with C etc., until they reached Z, at which point they went back to the beginning of the alphabet. The few participants who used this strategy would reach letters such as V and X and pause while trying to think of an animal. These participants produced a shorter list of words than those using the clustering strategies above. Again, this offers support from the information gathered from the participants in this study, towards Salthouse's (1985) processing rate theory of cognitive ageing.

4.2. Clinical Suitability of the Apparatus

In terms of the Fitts' Law Box's physical properties, it is a practical piece of dual task apparatus. The equipment is fairly lightweight, and compact in size; it can easily fit into a laptop case or similar carrier making it easily transportable. There is a simple control panel attached to the apparatus meaning that adjusting the flashing speed and entering the disc size is straightforward and quick, and as a result participants are not made to wait for any great length of time between trials, particularly during establishment of the Tapping (Flashing) and Tapping (Disc) Spans. Also, learning to enter information in to the control panel requires very little training. Manually changing the discs is done with ease, aided by the fact that they are stored in size order along the top of the Box. The apparatus can also be manoeuvred on the desk or table into a position that is comfortable for the participant to use it; the participants in this study varied in the position they chose, from close to their body to further away, and from directly in front of their body to the right or left hand sides. The physical properties therefore seem to make the equipment more appropriate for clinical use than bulky computerised tracking tasks (e.g. Baddeley et al., 1986) and paper-and-pencil visuomotor tasks which cannot be titrated for individual performance level (e.g. Della Sala et al., 2010).

Despite the many positive aspects to the equipment, one downfall occurred during the longer tapping tasks which lasted one minute. Although participants all began by tapping in time with the alternately flashing lights as instructed, once into the rhythm of tapping some would tap without looking at the lights and invariably speed up. Consequently, the participants would end up being out of sync with the flashing lights, resulting in poorer scores than they had been likely to achieve, as scores were based upon tapping the discs accurately and in time with the lights. This behaviour was seen on both the Tapping (Flashing) tasks when the lights flashed at individual Span speed and on the Tapping (Disc) task when the lights were set to flash alternately at Span speed + 0.1 second. It was observed that this issue seemed to particularly affect the older adults, though not exclusively, and happened several times with the same participants on single and dual task trials regardless of the instructions to tap in time with the lights being repeated. It seems similar to the problem that arose when tapping in time with a metronome, reported by Baddeley et al. (1997) when trialling a paper-and-pencil version of this dual task.

4.3. Limitations of this Study

One limitation of this study was that amongst the clinical and neuropsychological assessments completed by the participants, no measure of depression was used. As there was a significant difference in cognitive functioning between the young and elderly groups it would have been interesting to test for depression amongst the participant groups, because poor concentration and memory impairment are symptoms of depression that can negatively affect the results of neuropsychological tests (Woodruff-Pak, 1997). Although Kaschel et al. (2009) did not find a significant difference between healthy elderly adults and participants with chronic depression in their dual task study, depression in some participants could have affected the age effects found in all memory and executive function assessments, and possibly also the Digit Recall task scores from the dual task paradigm. Depression is the most common psychiatric disorder among older adults (Woodruff-Pak, 1997), and as the elderly participants in the study had an average age of 78 it would have been prudent to include a depression assessment such as the Beck Depression Inventory-II (BDI-II; Beck, Steer & Brown, 1996). The time taken to complete the range of tasks and tests in the current study took approximately one hour. The BDI-II takes approximately 10 minutes to administer (Strauss et al., 2006), so could have easily been fitted in to the testing session as participants had been advised to allow up to one hour and 30 minutes for completion of the study.

A second limitation is that due to the confines of an MSc study, it was not possible to match the participants on years of formal education. As previously mentioned, the significant difference arose through the young participants all being educated to at least undergraduate university level whereas there were very few older adults with a university or college education. This difference was probably due in part to the average age of the elderly group, and as most of the older participants were female they entered the workforce directly after leaving school in jobs that did not require further education. Had the participant groups been matched similarly for years of education there may not have been the same significant age difference on ACE-R (Mioshi et al., 2006) score or on the Digit Recall task of dual task paradigm, thus potentially changing the results.

Many of the participants in this study were selected opportunistically through contacts of the researcher. Some were tested in their own homes while others attended the University of Edinburgh's Psychology Department. Although distractions during in-home testing were kept to a minimum, it was not possible to equate the environments completely. Most of the participants tested in the Psychology Department were tested in the morning, in a small room where the temperature built up quickly. The desk space was small, and although large enough for the Fitts' Law Box the opportunity to move the equipment to a more comfortable position was restricted. In comparison, participants tested in their own homes sat at either a kitchen or dining-room table, and were able to reposition the equipment to a comfortable angle with little difficulty. Also, participants tested at home tended to carry out the tasks in the afternoon or evening. These differences in testing environment were not ideal, and may have influenced the results. However, due to the short time available to recruit and test participants these differences were unavoidable in this study.

4.4. Future Directions

The behavioural observations of those who took part in this study could lead to a possible solution of the problem of some participants tapping out of sync with the flashing lights and retain the measure of tapping accuracy. It would make sense that in order to tap the disc accurately, the participants would aim for the centre of the disc. It is therefore possible that if their vision was focussed on the centre of the disc, and were concentrating on aiming on target, the participants may have found it too difficult to look above the discs, at the lights, at the same time. It would be interesting, therefore, to see if this problem could be overcome by using lit targets. For example, using concentric circles the same sizes as the discs in this study outlined on the left and right of an acrylic surface, with a light under the centre of each circle, in a set-up similar to a lightbox. The surface area surrounding the largest target circles would need to be opaque while the target areas would be clear acrylic to let the light through. The desired size of target circles and the flashing speed could be controlled from an attached panel, as with the Fitts' Law Box. Since the target circles themselves would be lit from underneath, it may prove easier for participants to tap each target at the correct time. This in turn may improve scores and, as this problem occurred more frequently in the older adults, an improvement in scores may have reduced the performance difference between young and elderly groups. If age effects were found on such a task it would offer support to the idea that the Tapping (Disc) task employed in this study involved a speeded response, in which case a group of young participants would be expected to perform the task at a significantly higher level than older participants (Logie et al., 2007).

4.5. Conclusion

The results of the dual task experiment were not as predicted. Although performance on the Overall Tapping (Flashing) Dual Task showed a significant difference in percentage scores between the young and elderly participant groups as foreseen, there were significant age effects on both single tasks, as well as each of the dual tasks when carried out concurrently, which were unexpected. The findings of age effects on both the memory and visuomotor tasks comprising the Tapping (Disc) Dual Task were not anticipated. The results may be due to methodological problems with the Fitts' Law Box and associated Tapping tasks, such as the query over the involvement of a speeded response in the Tapping (Disc) condition. The results could also be attributed to the specific population who took part in this study as the young participants significantly outperformed the older adults on the single and dual tasks as well as every cognitive and neuropsychological assessment, suggesting significant baseline differences between the groups. Despite the unpredicted results, the physical properties of the Fitts' Law Box did prove it potentially suitable for clinical use. While retaining some existing features such as the simplistic style of control panel and overall structure of the Box are advised, some suggestions have been made for improvements and modifications to the dual task apparatus. These changes may make it easier to tap in time with the set flashing speed, as it was noted that some participants had difficulty with this. In conclusion, this study found that neither Tapping (Flashing) nor Tapping (Disc) conditions proved suitable for single task titration in order to replicate previous dual task findings. Further investigations are required to establish the root cause of these results and to explore a possible solution, as the effectiveness of the Fitts' Law Box as the visuomotor task in a dual task study has yet to be fully determined.

References

Army Individual Test Battery. (1944). *Manual of directions and scoring.* Washington, DC: War Department, Adjutant General's Office.

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology Section A, 49*, 5-28.

Baddeley, A.D. (1986). *Working memory.* Oxford, England: Oxford University Press.

Baddeley, A.D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Baddeley, A.D. (2007). *Working memory, though, and action*. Oxford, England: Oxford University Press.

Baddeley, A.D., Baddeley, H.A., Bucks, R.S., & Wilcock, G.K. (2001). Attentional control in Alzheimer's disease. *Brain, 124*, 1492-1508.

Baddeley, A.D., Bressi, S., Della Sala, S., Logie, R., & Spinnler, H. (1991). The decline of working memory in Alzheimer's disease: A longitudinal study. *Brain, 114*, 2521-2542.

Baddeley, A., Della Sala, S., Gray, C., Papagno, C., & Spinnler, H. (1997). Testing central executive functioning with a pencil-and-paper test. In P. Rabbitt (Ed) *Methodology of frontal and executive functions* (pp 61-80). Hove, England: Psychology Press.

Baddeley, A., Emslie, H., & Nimmo-Smith, I. (1994). *Doors and People.* Bury St. Edmunds, England: Thames Valley Test Company.

Baddeley, A.D. & Hitch, G.J. (1974). Working memory. In G. Bower (Ed) *The psychology of learning and motivation* (pp 47-89). New York, NY: Academic Press.

Baddeley, A.D., Logie, R., Bressi, S., Della Sala, S., & Spinnler, H. (1986). Dementia and working memory. *The Quarterly Journal of Experimental Psychology Section A, 38,* 603-618.

Beck, A.T., Steer, R.A., & Brown, G.K. (1996). *Beck Depression Inventory* (2nd ed.). San Antonio, TX: The Psychological Corporation.

Camicioli, R., Howieson, D., Lehman, S., & Kaye, J. (1997). Talking while walking: The effect of a dual task in aging and Alzheimer's disease. *Neurology, 48,* 955-958.

Craik, F.I.M. & McDowd, J.M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 474-479.

Della Sala, S., Foley, J.A., Beschin, N., Allerhand, M., & Logie, R.H. (2010). Assessing dual-task performance using a paper-and-pencil test: Normative data. *Archives of Clinical Neuropsychology.* Advance online publication.

Fitts, P.M. & Peterson, J.R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology, 67,* 103-112.

Haut, M.W., Kuwabara, H., Moran, M.T., Leach, S., Arias, R., & Knight, D. (2005). The effect of education on age-related functional activation during working memory. *Aging, Neuropsychology, and Cognition, 12,* 216-229.

Inasaridze, K., Foley, J.A., Logie, R.H., & Della Sala, S. (2010). Dual task impairments in vascular dementia. *Behavioural Neurology, 22,* 45-52.

Kaschel, R., Logie, R.H., Kazén, M., & Della Sala, S. (2009). Alzheimer's disease, but not ageing or depression, affects dual-tasking. *Journal of Neurology, 256,* 1860-1868.

Logie, R.H., Cocchini, G., Della Sala, S., & Baddeley, A.D. (2004). Is there a specific executive capacity for dual task coordination? Evidence from Alzheimer's disease. *Neuropsychology, 18,* 504-513.

Logie, R.H., Della Sala, S., MacPherson, S.E., & Cooper, J. (2007). Dual task demands on encoding and retrieval processes: Evidence from healthy adult ageing. *Cortex, 43,* 159-169.

MacPherson, S.E., Della Sala, S., Logie, R.H., & Wilcock, G.K. (2007). Specific AD impairment in concurrent performance of two memory tasks. *Cortex, 43,* 858-865.

Mioshi, E., Dawson, K., Mitchel, J., Arnold, R., & Hodges, J.R. (2006). The Addenbrooke's Cognitive Examination Revised (ACE-R): A brief cognitive test battery for dementia screening. *International Journal of Geriatric Psychiatry, 21,* 1078-1085.

Naveh-Benjamin, M., Craik, F.I.M., Guez, J., & Kreuger, S. (2005). Divided attention in younger and older adults: Effects of strategy and relatedness on memory performance and secondary costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 520-537.

Norman, W. & Shallice, T. (1986). Attention to action. In R.J. Davidson, G.E. Schwartz, & D. Shapiro (Eds) *Consciousness and self regulation: Advances in research and theory,* vol. 4, (pp 1-18). New York, NY: Plenum.

Perfect, T.J., & Maylor, E.A. (2000). Rejecting the dull hypothesis: The relation between method and theory in cognitive aging research. In T.J. Perfect & E.A. Maylor (Eds) *Models of cognitive aging* (pp 1-18) Oxford, England: Oxford University Press.

Reitan, R.M. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills, 8,* 271-276.

Salthouse, T.A. (1985). *A theory of cognitive aging.* Amsterdam, the Netherlands: Elsevier Science Publishers B.V.

Salthouse, T.A. (1994). The aging of working memory. *Neuropsychology, 8,* 535-543.

Strauss, E., Sherman, E.M.S., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary.* New York, NY: Oxford University Press.

Troyer, A.K., Moscovitch, M., & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology, 11*, 138-146.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale – III.* San Antonio, TX: The Psychological Corporation.

Woodruff-Pak, D. (1997). *The neuropsychology of aging.* Oxford, UK: Blackwell Publishing.

Appendix A. Example Participant Information Sheet

10/5/2010

Healthy Participant Information Sheet

Dear Sir or Madam

You are being invited to participate in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

What is the purpose of the study?
The aim of the research is to develop a new clinical tool which will assist the diagnosis of Alzheimer's disease. Currently, memory tasks are considered the most useful tests to detect early Alzheimer's disease. Unfortunately, although these tests are very sensitive, they lack specificity as memory problems can be present in other types of dementia and even in normal ageing, which can, at worst, lead to misdiagnosis. Research by our team and colleagues has found that people with Alzheimer's disease demonstrate difficulties doing two things at once: dual-tasking. This difficulty is not present in normal ageing. We hope to develop a clinical tool which assesses the ability to dual-task, derived from our experimental methods, that is a sensitive and specific assessment of Alzheimer's disease.

Why have I been chosen?
We would like you to take part because you are aged between 18 and 35, and generally in good health.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What will happen to me if I decide to take part?
You will be seen once by Alison Gemmell, MSc Human Cognitive Neuropsychology student. You will be asked to do a number of tasks which assess your concentration and memory abilities. In total, this will last around an hour. There are no disadvantages to you in taking part.
Will my taking part in this study be kept confidential?
All information that is collected about you during the course of the research will be kept strictly confidential. Any information about you that leaves the research office will have your any identifying information removed, so that you cannot be recognised from it.

What will happen to the results of the research study?
The results for the whole group will be analysed and compared to patient data. The results will be written up for publication in a peer-reviewed journal and used in the development of a new clinical assessment. It will not be possible to identify individual participants from these reports.

Who is organising the research?
Professor Sergio Della Sala, Professor Robert H. Logie, Dr John Starr and Dr Jennifer Foley from the University of Edinburgh are organising this study.

Who has reviewed this study?
Edinburgh University's School of Philosophy, Psychology and Language Sciences Research Ethics Committee, and Lothian Research Ethics Committee has reviewed this study.

Who do I contact for further information?
Please contact Dr Jennifer Foley for further information.

Thank you for reading this information sheet.

Yours faithfully

ALISON GEMMELL
Email: A.Gemmell-2@sms.ed.ac.uk

Dr Jennifer A. Foley
Research Fellow & Clinical Psychologist

Tel: 0131 650 8385
Fax: 0131 651 3230
Email: jfoley@ed.ac.uk

Appendix B. Participant Consent Form

10/5/2010

CONSENT FORM

Dual-task impairment in Alzheimer's disease:
An investigation on specificity and development of a clinical tool.

Participant Identification Number:

Name of Researcher: Alison Gemmell

Please tick box

1. I confirm that I have read and understand the information sheet dated 10.05.10 for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I agree to take part in the above study. ☐

4. Are you currently, or have been recently, involved in any other research? If so, please give details……………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………
……………

Name of Participant	Date	Signature
Name of Researcher	Date	Signature

Appendix C. Dual Task Scoresheet

Dual-task project score sheet

Participant Number

Age

Gender M F

Years of education

General health/medications?

Test	**Raw Score**	**Standard Score**
MMSE/ACE-R		
Doors & People ▪ People ▪ Shapes ▪ Recall		
WAIS-III Similarities		
Trail Making Test ▪ A ▪ B ▪ Total		
Verbal Fluency ▪ FAS		

Digit Span

Set up the computer to play the 'digit span' .wav files. Start with 'digit span = 3'.

This is a numbers task. I am going to play you some numbers. I'd like you to listen carefully and repeat them back to me. So, for example, if you heard 1-2-3, what would you say?

Participant should say 1-2-3. If correct, say ***yes, good, ok, have a go at these*** *and go onto trial 1. If incorrect, explain again. If they get them all correct 3/5 times, increase the span by 1 (i.e. 'digit span =4'). Keep doing this until they no longer get 3/5 correct. The longest span that they get 3/5 correct is that person's 'Digit Span'. Keep a note below of whether they passed/failed each trial.*

	3	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	358	9713	82691	861793	3945782	97834165	265749183	4869716523
2	581	7158	75468	453987	2473691	92563874	589214376	4691729538
3	217	2769	84973	578421	4876529	87564931	789352461	6954871823
4	519	9823	82749	312947	3289675	28693541	572614938	7291683245
5	456	3154	43861	365974	2941653	47325916	687913542	4596123578

SCORE

Digit Span =

Tapping (Flashing) Span

Set up the apparatus using disc size 2 (the second largest), with the flashing rate set at 0.8s, and time set for 10 seconds.

This task is a tapping task. I would like you to tap these two discs *(point)* ***in time with the flashing lights*** *(point)****, which will light alternately. The light on your right will illuminate first, at which point you should place the pen on the disc. After that, the lights will alternate quite quickly, but it is important to remember to tap the discs as accurately as possible. Each trial will last 10 seconds.***

If they get ≥ 90% 3/5 times, decrease the rate by 0.1s (i.e. 0.7s). Keep doing this until they no longer get 3/5 correct. If they don't get ≥ 90% 3/5 times on the first trial, then increase the rate by 0.1s (i.e. 0.9s). The quickest rate that they get 3/5 at ≥ 90% is that person's Tapping (Flashing) Span. Keep a note below of their score on each trial.

	Flashing rate	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Correct*
1							
2							
3							
4							
5							
6							
7							

SCORE Tapping (Flashing) Span =

Tapping (Disc) Span

Set up the apparatus using disc size 2 (the second largest), with the flashing rate set at (Tapping (Flashing) Span rate + 0.1s), and time set for 10s.

Again, please tap the two discs in time with the flashing lights. It is important to remember to tap the discs as accurately as possible. Each trial will last 10 seconds.

If they get ≥ 90% 3/5 times, decrease the size of the disc. Keep doing this until they no longer get 3/5 correct. The smallest disc that they get 3/5 at≥ 90% is that person's Tapping (Disc) Span. Keep a note below of their score for each trial.

	Disc Size	*Trial 1*	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Correct*
1							
2							
3							
4							
5							
6							
7							

SCORE Tapping (Disc) Span =

<u>Digit Recall</u> (single task)

Set up the computer to play the 'Digit Span PPT Presentations'. Under the person's Digit Span, choose the 'Single Task' version of the PPT files.

Ok. Let's go back to the numbers task. I'd like you to listen carefully and repeat these numbers back to me. This time the sequences will always be *[Digit Span]* ***numbers long, and the task will last for one minute.***

Using a stopwatch, play the digit sequences for 1 minute. As soon as the participant makes their response, record it below and press the space bar to move onto the next digit sequence.

Digit Span = 2	*Correct*	*Response*		*Digit Span = 3*	*Correct*	*Response*
1	83			1	829	
2	28			2	132	
3	68			3	152	
4	34			4	641	
5	26			5	923	
6	97			6	673	
7	53			7	157	
8	83			8	895	
9	94			9	786	
10	92			10	689	

Digit Span = 4	*Correct*	*Response*		*Digit Span = 5*	*Correct*	*Response*
1	6241			1	62317	
2	2359			2	95716	
3	7132			3	79316	
4	3715			4	85293	
5	7594			5	91635	
6	3926			6	16592	
7	8753			7	73592	
8	5476			8	64135	
9	6982			9	35279	
10	6734			10	46273	

Digit Span = 6	*Correct*	*Response*		*Digit Span = 7*	*Correct*	*Response*
1	587261			1	5163479	
2	492617			2	2468795	
3	148239			3	9827631	
4	761254			4	1285394	
5	495321			5	8243167	
6	758469			6	3185624	
7	736184			7	9184562	
8	758126			8	9627815	
9	587196			9	8125937	
10	419657			10	7198325	

Digit Span = 8	*Correct*	*Response*		*Digit Span = 9*	*Correct*	*Response*
1	65148279			1	679174382	
2	28653197			2	239874615	
3	85729136			3	539748216	
4	71498562			4	364895721	
5	65783492			5	965382471	
6	74521639			6	537162849	
7	18549237			7	812479653	
8	62879534			8	487961325	
9	85724961			9	825913764	
10	87632915			10	635128794	

Digit Span = 10	*Correct*	*Response*		*Digit Span = 10*	*Correct*	*Response*
1	4982176453			7	6815947123	
2	5731298426			8	6718345492	
3	8182387465			9	1948356727	
4	3824675219			10	5928471136	
5	3257148569					
6	1782863945					

SCORE Total Digits Heard = ____________

Total Digits Recalled Correctly =________________

Digit Recall (single task) = %

Tapping (Flashing)

(single task)

Set up the apparatus using disc size 2 (the second largest), with the flashing rate set at Tapping (Flashing) Span, and time set for 1 minute.

Good. Ok, let's go back to the tapping task. Again, I would like you to tap these two discs *(point)* ***in time with the flashing lights*** *(point)**, which will light alternately. The lights will alternate quite quickly, but it is important to tap the discs accurately. This task will last for one minute.***

SCORE ***Tapping (Flashing) (single task) = %***

Digit recall + Tapping

(Flashing) (dual task)

Tapping task: keep the apparatus set with disc size 2 (the second largest), with the flashing rate set at Tapping (Flashing) Span, and time set for 1 minute.

Digit recall task: set up the computer to play the 'Digit Span PPT Presentations'. Under the person's Digit Span, choose the 'Dual Task' version of the PPT files.

Good. Ok, now I want you to keep tapping the discs, in time with the flashing lights, but at the same time, I'd like you to repeat the numbers. The lights will start before the numbers, so you'll have a chance to get into the rhythm of the lights before you hear the first set of numbers. It is important that you do both the tapping and numbers as well as you can. The task will last for one minute. OK? Let's have a go.

Start the tapping task, and then after around 5 seconds, start the digit sequences. As soon as the participant makes their response, record it below and press the space bar to move onto the next digit sequence.

Digit Span = 2	Correct	Response		Digit Span = 3	Correct	Response
1	35			1	594	
2	63			2	487	
3	16			3	357	
4	93			4	674	
5	58			5	234	
6	35			6	398	
7	21			7	258	
8	64			8	759	
9	19			9	592	
10	71			10	435	

Digit Span = 4	Correct	Response		Digit Span = 5	Correct	Response
1	9873			1	74638	
2	6159			2	61534	
3	7289			3	12846	
4	8452			4	86231	
5	6918			5	14735	
6	3867			6	39275	
7	7358			7	43517	
8	2598			8	58931	
9	1547			9	16528	
10	8231			10	51697	

Digit Span = 6	Correct	Response		Digit Span = 7	Correct	Response
1	485273			1	9173258	
2	184923			2	6124897	
3	154239			3	1673528	
4	428567			4	2564879	
5	785214			5	7946125	
6	837124			6	4971682	
7	742183			7	5392764	
8	425347			8	9468253	
9	389461			9	4852739	
10	246879			10	1849237	

Digit Span = 8	Correct	Response		Digit Span = 9	Correct	Response
1	38679452			1	475821963	
2	27614853			2	475319682	
3	94658312			3	329416578	
4	24675913			4	674352918	
5	49658173			5	753214968	
6	65491328			6	243961758	
7	12796385			7	349265831	
8	36918542			8	749265831	
9	28963541			9	825913764	
10	84291756			10	487961325	

Digit Span = 10	Correct	Response		Digit Span = 10	Correct	Response
1	6872911435			7	5324876129	
2	7854976321			8	2583764919	
3	2841745396			9	1532784696	
4	3541817926			10	1948273365	
5	3192768485					
6	8357241659					

SCORE

Number of digits heard = ____________

Number of digits recalled correctly =________________

Digit Recall (dual task) = ***%***

SCORE ***Tapping (Flashing) (dual task) =*** ***%***

Tapping (Disc)
(single task)

Set up the apparatus at using discs set at (Tapping (Disc) Span) with the flashing rate set at (Tapping (Flashing) Span rate + 0.1s), and time set for one minute.

Good. Ok, let's do the tapping task on its own again. Again, I would like you to tap these two discs *(point)* ***in time with the flashing lights*** *(point)****, which will light alternately. The lights will alternate quite quickly, but it is important to tap the discs accurately. This task will last for one minute.***

SCORE ***Tapping (Disc) (single task) =*** ***%***

Digit recall + Tapping (Disc) **(dual task)**

Tapping task: keep the discs set at Tapping (Disc), with the flashing rate set at Tapping (Flashing) Span + 0.1s, and time set for 1 minute.

Digit recall task: set up the computer to play the 'Digit Span PPT Presentations'. Under the person's Digit Span, choose the 'Dual Task' version of the PPT files.

Good. Ok, now I want you to do that again, for another minute. Again, it is important that you do both the tapping and numbers as well as you can.

Make sure you record each response and move onto the next digit span sequence as soon as possible.

Digit Span = 2	Correct	Response		Digit Span = 3	Correct	Response
1	35			1	594	
2	63			2	487	
3	16			3	357	
4	93			4	674	
5	58			5	234	
6	35			6	398	
7	21			7	258	
8	64			8	759	
9	19			9	592	
10	71			10	435	

Digit Span = 4	Correct	Response		Digit Span = 5	Correct	Response
1	9873			1	74638	
2	6159			2	61534	
3	7289			3	12846	
4	8452			4	86231	
5	6918			5	14735	
6	3867			6	39275	
7	7358			7	43517	
8	2598			8	58931	
9	1547			9	16528	
10	8231			10	51697	

Digit Span = 6	Correct	Response		Digit Span = 7	Correct	Response
1	485273			1	9173258	
2	184923			2	6124897	
3	154239			3	1673528	
4	428567			4	2564879	
5	785214			5	7946125	
6	837124			6	4971682	
7	742183			7	5392764	
8	425347			8	9468253	
9	389461			9	4852739	
10	246879			10	1849237	

Digit Span = 8	Correct	Response		Digit Span = 9	Correct	Response
1	38679452			1	475821963	
2	27614853			2	475319682	
3	94658312			3	329416578	
4	24675913			4	674352918	
5	49658173			5	753214968	
6	65491328			6	243961758	
7	12796385			7	349265831	
8	36918542			8	749265831	
9	28963541			9	825913764	
10	84291756			10	487961325	

Digit Span = 10	Correct	Response		Digit Span = 10	Correct	Response
1	6872911435			7	5324876129	
2	7854976321			8	2583764919	
3	2841745396			9	1532784696	
4	3541817926			10	1948273365	
5	3192768485					
6	8357241659					

Total Digits Heard = ____________

SCORE ***Total Digits Recalled Correctly =***________________

Digit Recall (dual task) = ***%***

SCORE ***Tapping (Disc) (dual task) =*** ***%***

FLASHING

SCORE *100 – [(Digit Recall (single task) ____- Digit Recall (dual task) _____) x100*

DIGIT RECALL (FLASHING)

Digit Recall (single task)_________]

Dual task performance of digit recall (flashing) =_________________%

TAPPING (FLASHING)

100 – [(Tapping (single task) ______- Tapping (dual task) _________) x100

Tapping (single task)_________]

Dual task performance of tapping (flashing) = ____________________%

OVERALL (FLASHING) DUAL TASK PERFORMANCE

(Dual task performance of digit recall (flashing)______________ %+

Dual task performance of tapping (flashing) = ________________ %)

2

Overall dual task performance (flashing)= ___________________***%***

DISC	
SCORE	*100 - [(Digit Recall (single task) _____- Digit Recall (dual task)______) x100*
	____
DIGIT	*Digit Recall (single task)__________]*
RECALL	
(DISC)	*Dual task performance of digit recall(disc) = _____________________%*

TAPPING	*100 – [Tapping (single task) ________-Tapping (dual task) ________) x100*
(DISC)	____
	Tapping (single task)__________]
	Dual task performance of tapping (disc) = ______________________%

OVERALL	*(Dual task performance of digit recall (disc)_______________ %+*
(DISC)	*Dual task performance of tapping (disc) = _________________ %)*
DUAL TASK	____
PERFORMANCE	2
	Overall dual task performance (disc)= ____________________%